Power loss models for the portable phone "Pointel" in a typical indoor environment

Gh. Zaharia, G. El Zein and J. Citerne

Laboratoire Composants & Systèmes pour Télécommunications
URA CNRS 834, INSA, 35043 Rennes Cédex, FRANCE

Abstract: **Using a simplified and improved measurement system operating in the frequency domain, a typical obstructed line-of-sight (OLOS) indoor environment is investigated. From the measured data, three large-scale models for the power-distance relationship are discussed. In order to obtain a comparison between these models and to select the most accurate model, two criteria are proposed: the correlation coefficient and the Euclidean distance between the measured and the estimated power loss values. These two criteria indicate the same hierarchy for the considered models.**

I. INTRODUCTION

The use of the portable phones or the wireless local area networks within buildings requires a study of the indoor radio propagation. The main objective of the indoor radio wave propagation measurements is to determine the radio coverage and the data rate limitations in various buildings. The radio coverage is related to the power-distance relationship in the area, while the data rate is limited by the frequency selective fading multipath characteristics of the channel [1].

The measurements described in this paper were performed for the portable phone Pointel, developed by SAT-Paris. This system operates in the 864 - 868 MHz frequency band and has 40 adjacent channels, each one with 100 KHz bandwidth. The aim of these measurements is to determine the radio coverage in some typical indoor environments. In a previous paper [2], three indoor environments with both line-of-sight (LOS) and obstruction of the direct path were analysed. In this paper, a new OLOS environment is considered. From the measured data, three large-scale models for the power-distance relationship are presented and compared.

II. DESCRIPTION OF THE MEASUREMENTS

The measurement system is built up around an HP 8753C network analyzer which generates a swept frequency signal from 864 MHz to 868 MHz in 801 equally spaced steps and analysis the received signal. The output of the network analyzer (fig.1) is connected to the transmitting (Tx) antenna with 3.5 dBi gain through a 50 m coaxial cable with 8 dB attenuation. The calibration is performed at the output of this cable. The power of the signal transmitted by the first port of the HP 85046A S-parameter test set is +20 dBm. Due to the attenuation of the 50 m coaxial cable connected between the transmitting antenna and the port 1, the actual transmitted power is +12 dBm. The signal from the fixed receiving antenna is returned through a 4.5 m coaxial cable to the network analyzer in order to determine the S_{21} parameter. For the power loss measurements, for each location of the Tx antenna, the magnitude of S_{21} must be recorded. The measured data are read by the computer Tektronix 4041 via the IEEE-488 interface bus and stored on the hard disk (TEK 4041 Disk Drive Unit) for further analysis.

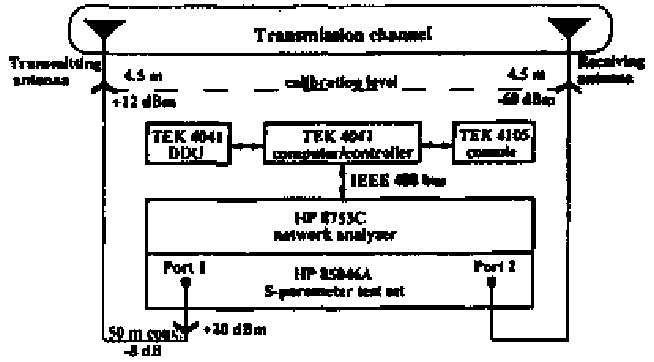

Fig. 1. Measurement system

In order to obtain sufficient data in a reasonable time, the acquisition program presents some important features [3]. The data transfer is realised in the fastest format of the network analyzer: the internal binary format. This solution reduces the transfer time at 0.39 s (for 801 values). The data is received in a string variable and recorded with a low-level statement. Therefore, the recording time is reduced at 1.67 s for one curve (801 points).

Unfortunately, the computer can not use the data recorded in this format. Therefore, after the end of the measurement campaign, in the laboratory (practically, during the night), the data must be returned to the network analyzer and transformed in the ASCII format. A new transfer to the computer permits to create ASCII files in a separate zone of the hard disk. The main advantage of this strategy is the important reduction of the total time required for a measurement during the measurement campaign.

Another feature of the acquisition program is the utilisation of the learn string to read and store the state of the network analyzer. The learn string includes all front panel settings. Before the measurement campaign, it can be read by the computer from the network analyzer via the IEEE-488 interface and recorded in a file. At the beginning of the measurements, the learn string is read from this file and putted back into the network analyzer via the IEEE-488 interface.

The time required for the set-up of this measurement system can be further reduced by reading the calibration data. This operation can be performed only once, in the laboratory. At the beginning of a measurement campaign, after the instrument state, the program can also restore the calibration, so a slow operation can be avoided.

A final feature is the utilisation of this program as a part of the special program AUTOLD of the Tektronix 4041. This program is automatically loaded and run. Thus, the task of the operator is much simplified.

Fig. 2 presents the indoor environment chosen for these measurements, located in the first floor of the principal building of INSA (National Institute of Applied Sciences). The Rx antenna was placed at one extremity of the first room and the Tx antenna was moved at several locations on a straight line, in four successive rooms. For each room, 50 locations for the Tx antenna were chosen on a logarithmic scale. Both antennas are $\lambda/4$ units which exhibit an omnidirectional radiation pattern in the horizontal plane and approximately figure-eight shaped beam in the vertical plane. They were placed at the same height H, therefore the influence of the radiation pattern on the received power was eliminated for the direct path. For the antennas height, two values were considered: H=1.5 m and H=1.9 m. During the measurements, both antennas were kept fixed.

Concerning the time invariance of the channel, the measurements were performed during the week-end, in order to avoid the effects of the presence of people. The surrounding environment was kept stationary by preventing movements during the measurements.

III. DATA ANALYSIS

1. Global analysis

For power loss measurements, for each frequency f_j ($1 \le j \le m$) chosen in the considered frequency band and for each position of the Tx antenna, placed at a distance d_i ($1 \le i \le n$) from the Rx antenna, a value p_{ij} for the power loss is obtained. For each distance d_i, the m power loss values p_{ij} can be averaged. Consequently, an average power loss $\bar{P}(d_i)$ is obtained. As usual [1, 2, 4], assuming that, for a given distance d between antennas, the average power loss can be expressed as:

$$\bar{P}(d) = A\, d^{\alpha} \tag{1}$$

when the logarithm of (1) is taken, the following linear relationship results:

$$\bar{P}(dB) = A(dB) + \alpha[10\log_{10}(d)] \tag{2}$$

Using a linear regression analysis [5] between the average power loss and the distance, the parameters A and α can be computed. Due to the calibration, the attenuation of the coaxial cable was eliminated, so A obtained above represents a realistic value.

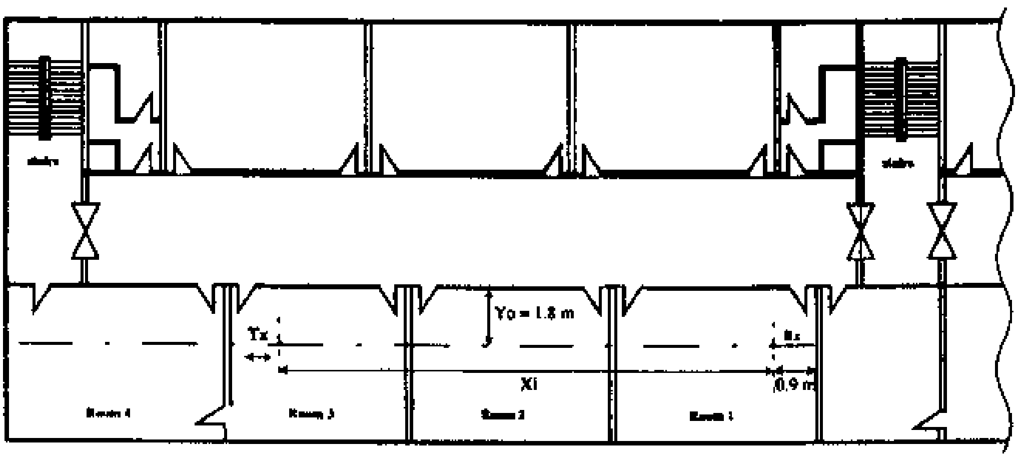

Fig. 2. Indoor environment considered in the building of INSA

For H=1.5 m, the linear regression analysis gives α=2.564 and A=35.64 dB. The standard deviation of the average power loss from the regression estimates is ems =5.577 dB. The correlation coefficient r=0.89 indicates that increasing power loss is highly correlated with increasing distance. Similar results are obtained for H=1.9 m.

2. Analysis for each room with an unique exponent

This analysis takes into account the attenuations P_{AB}, P_{BC} and P_{CD} introduced by the walls which separate the four rooms. As in [6], if we consider an unique exponent α for each room, due to these attenuations, the power loss can be modelled as:

$$\overline{P}(d) = A + \alpha[10\log_{10}(d)]\ , \quad \text{for Room 1} \qquad (3)$$

$$\overline{P}(d) = B + \alpha[10\log_{10}(d)]\ , \quad \text{for Room 2} \qquad (4)$$

$$\overline{P}(d) = C + \alpha[10\log_{10}(d)]\ , \quad \text{for Room 3} \qquad (5)$$

$$\overline{P}(d) = D + \alpha[10\log_{10}(d)]\ , \quad \text{for Room 4} \qquad (6)$$

The above relations allows us to accept different attenuations for the separating walls:

$$P_{AB} = B - A \qquad (7)$$

$$P_{BC} = C - B \qquad (8)$$

$$P_{CD} = D - C \qquad (9)$$

Therefore this model is more general and describes better the power-distance relationship. If:

$$B - A = C - B = D - C \qquad (10)$$

one can obtain the model described in [6].

For the same height H=1.5 m, the obtained results are given in fig. 3. The vertical dotted lines represent the walls. This figure shows a scatter plot of the power loss versus distance on a log scale and the MMSE lines fitted to the data.

This new power loss model indicates smaller values for α (1.55 for H=1.5 m and 1.77 for H=1.9 m), while the global model gives more important values (2.56 for H=1.5 m and 2.45 for H=1.9 m), due to the walls attenuations. It is interesting to note that similar smaller values for α (about 1.55) were obtained on the corridor, at the same floor of the environment considered in fig. 2 [2]. For the corridor, for all measurements, the line-of-sight (LOS) was assured.

The results obtained with this model suggest that the propagation conditions for this OLOS indoor environment resemble those of the corridor (LOS environment). The difference consists in the presence of the separating walls which behave as attenuators. Using the results given in fig. 3 and the relations (7) - (9) it is possible to estimate their attenuations: P_{AB} = 4.57 dB, P_{BC} = 6.25 dB and P_{CD} = 1.13 dB. The first values reflect a real situation: the second wall has practically the same thickness as the first one but on each side it has a blackboard with a metallic support, while the first dividing wall has only one blackboard (with one metallic support). Therefore, $P_{BC} > P_{AB}$.

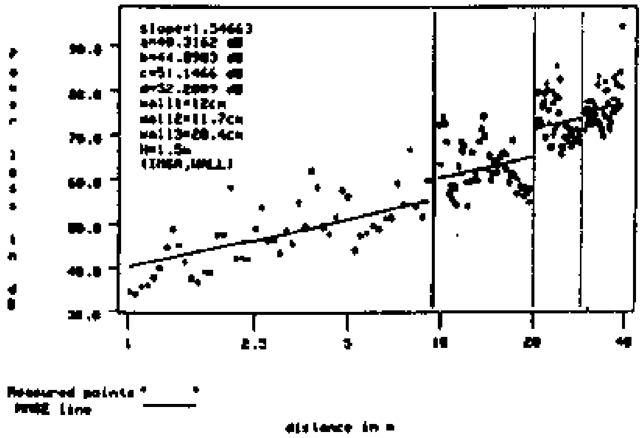

Fig. 3. Power loss versus distance on a log scale (unique exponent)

One can also note that the thickness of the third dividing wall is about the double of the thickness of the first dividing wall. Each one has an identical blackboard with an identical metallic support. Therefore, it is natural to expect $P_{CD} > P_{BC}$. However, the value obtained from measurement is smaller than P_{BC}. This can be determined by the important distance between the Rx antenna and the third dividing wall.

The obtained value for P_{CD} suggests to repeat the measurements with the Rx antenna placed in the third room, next to the second dividing wall and Tx antenna moved at several locations on a straight line, in the third and the fourth room (so a similar scenario used for P_{AB}). In order to obtain a better estimation for P_{BC}, the same scenario can also be used for the second wall. Using the new values for P_{BC} and P_{CD} it is possible to repeat the analysis with an unique exponent in order to obtain a more accurate model.

In fig. 3 one can also note the important variation of the power loss with the distance. In the corridor, these variations are less important. This suggests the presence of the steady-stead waves, due to multiple reflections on the dividing walls.

3. Analysis for each room

In this case, the regression analysis is performed independently for the data obtained in each room. This time we drop the idea of an unique exponent. The analysis gives a value for A_k and α_k for each room k:

$$\tilde{P}(d) = A_k + \alpha_k\,[10\log_{10}(d)], \quad \text{for Room k}, \quad k = \overline{1,4} \quad (11)$$

The obtained results are given in Table 1. For the first room, the results are quite well. Due to the steady-stead waves, the root mean square error (ems) is quite important, while the correlation coefficient r is quite small, while the global analysis gives r about 0.9. For both heights, the slope α is about 2, so the propagation conditions resemble those associated with free-space.

TABLE I
RESULTS OF THE ANALYSIS FOR EACH ROOM

Param.	Room 1		Room 2		Room 3		Room 4	
	H=1.5 m	H=1.9 m	H=1.5 m	H=1.9 m	H=1.5 m	H=1.9 m	H=1.5 m	H=1.9 m
slope	2.016	1.919	-2.06	0.363	-5.56	-0.54	4.759	4.062
A(dB)	38.07	39.11	86.14	59.58	149.35	80.22	3.25	12.05
r	0.746	0.748	-0.34	0.072	-0.498	-0.053	0.395	0.337
ems(dB)	5.078	4.804	4.988	4.488	4.064	4.239	4.081	4.184

For the other rooms, the correlation is week. For example, for the second room, the correlation and the slope are negative. Due to the important attenuation of the metallic support of the blackboard, the received signal after the first wall is quite weak. This attenuation is less important with increasing distance, so in the middle of the room the power loss is less important. This can explain the negative value of the slope and the correlation coefficient.

IV. COMPARISON BETWEEN THE MODELS

In the previous section, from the measured power loss values, three large-scale models for the power loss-distance relationship were described. In this section, two different criteria are proposed: the correlation coefficient between the measured and estimated power loss values and the Euclidean distance between these two parameters, thought as two vectors.

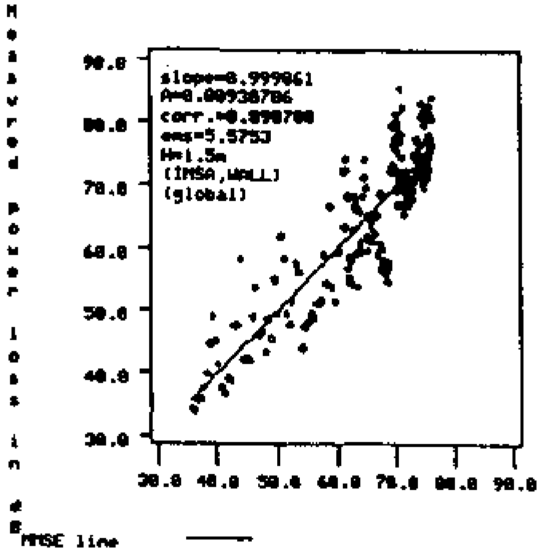

Fig.4. Correlation between the measured and estimated power loss values (H=1.5 m)

For the first model and for H=1.5 m, the results of the regression analysis are shown in fig. 4. Similar results were obtained for the other models. All the results are given in Table 2.

TABLE 2
COMPARISON BETWEEN THE MODELS

Param.	Model 1		Model 2		Model 3	
	H=1.5 m	H=1.9 m	H=1.5 m	H=1.9 m	H=1.5 m	H=1.9 m
r	0.891	0.909	0.908	0.919	0.928	0.923
ems(dB)	5.575	4.794	5.147	4.527	4.569	4.431

The two criteria indicate the same hierarchy for the proposed models: 1-2-3 (the third model is the best). This is a normal result, because the third model uses 8 independent parameters (A, B, C, D and one exponent for each room).

V. CONCLUSION

Using an improved measurement system, a typical indoor environment has been chosen for experimental investigation. Three large-scale models for the power-distance relationship were considered. The comparison between these models indicates that the third model gives the best correlation and the smallest Euclidean distance between the measured and estimated power loss values. Using these results, the radio coverage in different buildings can be obtained with an enough accuracy.

VI. REFERENCES

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